Bay of Fundy Salmon Aquaculture Monitoring Program

1991 - 1992

Canada-New Brunswick
Water/Economy Agreement

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New Nouveau Brunswick
C·A·N·A·D·A

Bay of Fundy Salmon Aquaculture Monitoring Program

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EXECUTIVE SUMMARY

In 1991, the New Brunswick Department of the Environment initiated a multi-year monitoring program designed to assess the environmental impacts of the cage rearing of Atlantic Salmon in the Bay of Fundy. The program was implemented to help the New Brunswick industry avoid the environmental difficulties experienced by the salmon aquaculture industry in other countries. The monitoring program incorporated analysis of seafloor sediments, biological samples, physical/chemical oceanography and operational parameters which enabled development of a qualitative rating system. This system was used to assess the impact of each cage site on its local marine ecosystem.

A total of 48 sites were monitored. Eleven sites showed a low level of environmental degradation, twenty-nine showed a moderate level and eight showed a high degree of degradation. The range of degradation from low to high was measured by the reduced availability of suitable seafloor habitat. For the low to moderately impacted sites, the bottom degradation was restricted primarily to an area directly beneath the cage sets. Bottom conditions for those sites which showed a high degree of degradation were such that only pollution tolerant species were able to occupy the seafloor. The impact at these sites was considered significant and the areas were identified as requiring remedial action. Actions such as removal of debris from the bottom, off-site net cleaning, less wasteful feeding techniques, and cage relocation were recommended to site operators.

The second year of the program (1992-1993) will involve more intensive monitoring at those sites which showed a high level of degradation. In addition to the collection and analysis of sediments, bottom dwelling organisms and water samples, current meters and sedimentation traps will be installed at selected sampling locations. Results from this work will improve the knowledge of current patterns and waste deposition under various site conditions.

The results and conclusions contained in this report were arrived at following analysis of all the data that was collected during the 1991 field program. The data was analyzed from the following:

- 422 benthic invertebrate samples for determination of species composition and indicator species
- 751 sediment samples for determination of % organic composition, % silt/clay, % water content and REDOX potential
- 612 water quality samples for measurement of salinity, temperature and dissolved oxygen

- 204 Secchi disc readings for determination of water clarity
- 576 depth soundings
- 46 visual observations of bottom conditions over 100m distance
- 11 hours of underwater videotaping

This data; however, has not been included in the report as the Department felt it important to respect the sensitivity of individual site information and the potential for economic impact.

Anyone interested in obtaining additional information is required to contact the Water Resource Monitoring Section, Department of the Environment in Fredericton.

RÉSUMÉ

En 1991, le ministère de l'Environnement du Nouveau-Brunswick a lancé un programme pluriannuel de surveillance pour évaluer les effets que peut avoir sur l'environnement l'élevage en cages du saumon de l'atlantique dans la baie de Fundy. Ce programme a été mis en oeuvre pour aider l'industrie du Nouveau-Brunswick à prévenir les problèmes environnementaux connus par l'industrie de la salmoniculture dans d'autres pays. Le programme de surveillance comprenait l'analyse de sédiments sur les fonds océaniques, le prélèvement d'échantillons biologiques ainsi que l'examen des paramètres opérationnels et l'océanographie chimique/physique qui ont permis la mise au point d'un système d'évaluation qualitative. Celui-ci a servi à évaluer l'effet de chaque site d'élevage en cages sur son écosystème marin local.

Un total de 48 sites ont été surveillés. Onze sites ont révélé un faible niveau de dégradation de l'environnnement, 29 ont révélé un niveau modéré de dégradation tandis que huit ont révélé un degré élevé de dégradation. L'écart de la dégradation, de faible à élevé, a été déterminé par la disponibilité réduite d'un habitat adéquat sur le fond océanique. Dans le cas des sites caractérisés par un niveau de dégradation de faible à modéré, la dégradation du fond était restreinte principalement à une zone directement en dessous des cages. Les conditions du fond océanique des sites qui ont révélé un degré élevé de dégradation étaient telles que seules les espèces résistantes à la pollution pouvaient occuper le fond. L'effet à ces sites a été jugé important et il a été déterminé que les zones nécessitaient des mesures de redressement. Les mesures recommandées aux exploitants des sites comprenaient entre autres l'enlèvement des débris du fond, le nettoyage des filets en dehors du site, l'utilisation de méthodes d'alimentation réduisant le gaspillage et le déplacement des cages.

Au cours de la deuxième année (1992-1993), le programme comportera une surveillance plus étroite des sites qui ont révélé un degré élevé de dégradation. Outre la collecte et l'analyse des sédiments, d'organismes qui vivent sur le fond et d'échantillons d'eau, des courantomètres et des bassins de décantation seront installés aux lieux d'échantillonage choisis. Ces travaux fourniront plus d'information sur les modes de courant et les dépôts de déchets dans diverses conditions sur le site.

Les résultats et les conclusions de ce rapport ont été établis après l'analyse de toutes les données recueillies dans le cadre du programme sur place de 1991. Les données ont été analysées à partir de ce qui suit:

- 422 échantillons d'invertébrés benthiques afin de déterminer la composition des espèces et les espèces indicatrices

- 751 échantillons de sédiments pour déterminer le pourcentage de composition organique, le pourcentage de limon/d'argile, le pourcentage de la teneur en eau et le potentiel REDOX
- 612 échantillons de la qualité de l'eau pour mesurer la salinité, la température et l'oxygène dissous
- 204 relevés du disque de Secchi pour déterminer la clarté de l'eau
- 576 mesures de la profondeur
- 46 observations visuelles des conditions de fond sur une distance de 100m
- 11 heures d'enregistrement magnétoscopique sous l'eau

Ces données n'ont toutefois pas été incluses dans le rapport, puisque selon le ministère, il était important de respecter le caractère délicat de l'information sur chaque site et de tenir compte de l'impact économique possible.

Toute personne intéressée à obtenir d'autre information devrait communiquer avec la Section de la surveillance des ressources en eau, ministère de l'Environnement, à Fredericton.

INTRODUCTION

2.1 Growth of the Industry

The salmon cage aquaculture industry in the Bay of Fundy has experienced rapid growth. The introduction, in the late 1970's, of one experimental site with an annual production of 5 tonnes, has developed to a harvest level of 9,500 tonnes per year with a value of nearly 100 million dollars in 13 years. (Figure 1)

2.2 Salmon Life Cycle

The success of the cage salmon aquaculture industry is heavily dependent on the success of the freshwater smolt production industry. The Atlantic Salmon, an anadromous species, spends a portion of its life in fresh water and a portion of its life in salt water. Life for a wild salmon begins in freshwater.

This is also true of hatchery rearing. Fertilized eggs, collected from brood stock at cage sites are transferred to freshwater hatchery facilities in November. Here, they are incubated and hatched under strictly controlled conditions. These hatchlings soon begin to feed and grow. In May, these fish are moved to outside tanks until it is time to transport them to salt water cages (usually the following April) as "smolt".

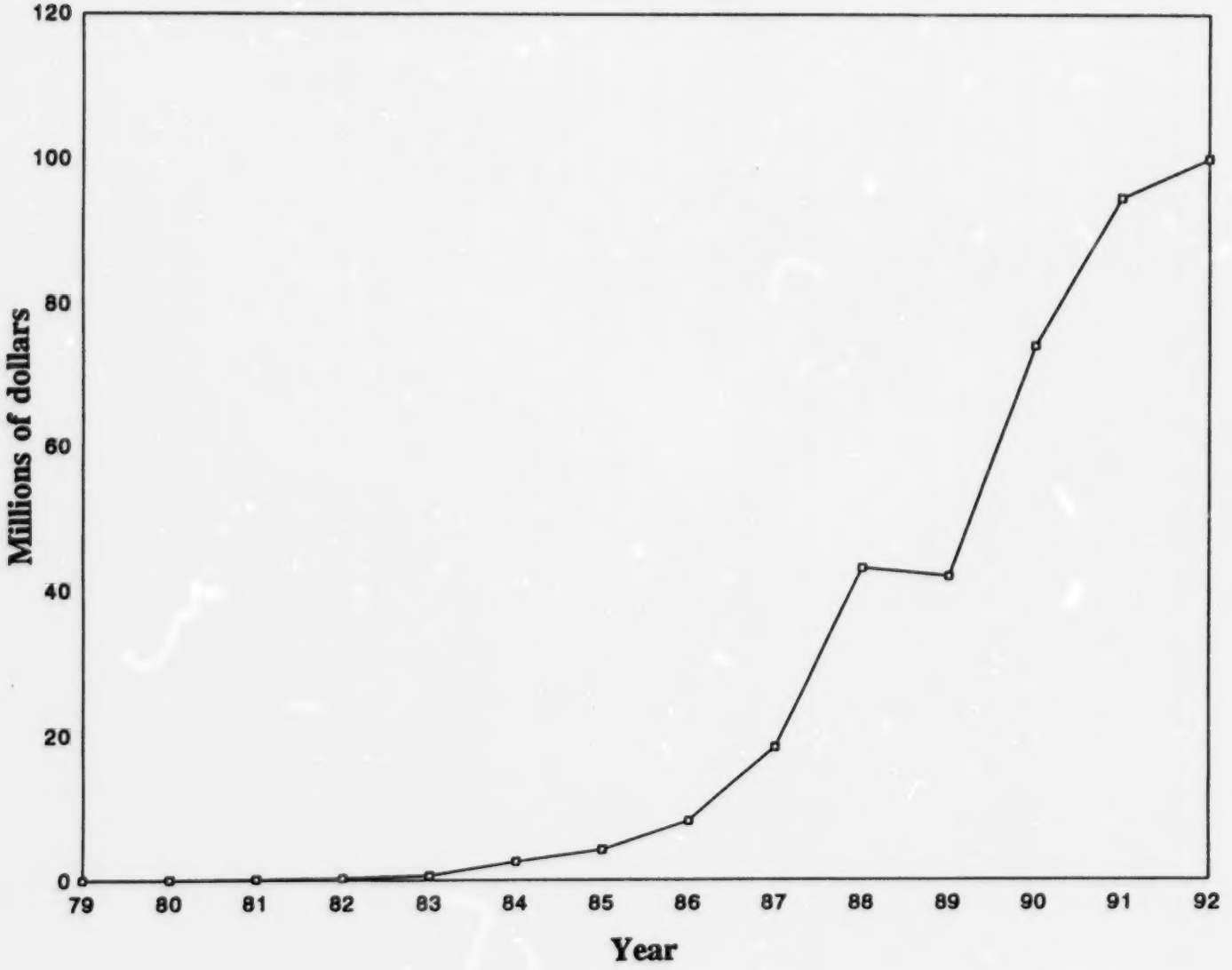
The egg to smolt process, which normally takes 3 years in the wild, takes only 18 months under hatchery conditions. The smolt are then kept in the salt water cages for at least a year in preparation for marketing.

The continued growth of the industry has been vital to the economic well being of the Bay of Fundy area by providing 1,500 direct and indirect jobs as well as supporting numerous spin-off industries. With this continuing expansion has come an increasing awareness of the need to protect the environment and maintain the integrity of the water quality around cage sites.

2.3 Potential Problems

The lack of foresight and expansion pressure in the aquaculture industry in Europe has resulted in serious environmental problems and, in some cases, economic failure. To avoid the difficulties which have plagued the European fish farming community, the Province of New Brunswick implemented a multi-year aquaculture monitoring program to assess the impacts of salmon cage operations on the Bay of Fundy marine ecosystem. The objective of the sampling program was to collect the type of information which could provide a site specific assessment of the industry's impact on the natural environment.

Figure 1 - Value of Salmon Aquaculture Industry



2.4 Baseline Survey

Following consultation with scientists from the Biological Station in St. Andrews, staff of the Department of Fisheries and Aquaculture and industry representatives, goals were established for the baseline survey.

These were:

- to qualitatively determine the area of seabed impacted by the cage operations.
- to document the physical oceanographic characteristics of each cage site.
- to document the operational characteristics of each cage site through contact with workers including production information supplied by each operator.
- to categorize the benthic community structure in the vicinity of the cage site for comparison with a distant control site.

The study area included all of the 48 existing operational sites in the Bay of Fundy of which 16 sites were in the West Isles; 6 sites in Passamaquoddy Bay/Letete Passage; 5 sites in Backbay; 7 sites in Bliss Harbour; 10 sites in Limekiln Bay/L'Etang Harbour, and 4 in Deadmans Harbour/Beaver Harbour.

Individual locations were assessed on a variety of criteria which included:

water depth
current speed and direction
wave climate
seafloor characteristics
water quality
conflicting uses
husbandry practices

This baseline data served to measure the extent of environmental degradation at each site and subsequently identify those sites in need of remedial action (Figure 2).

Figure 2 - Aquaculture Monitoring Program

Consumption by native species

Loss of soluble feed and faecal material

WASTE DEPOSITION

? ENVIRONMENTAL IMPACT ?

AQUACULTURE MONITORING PROGRAM

Operational Parameters	Phys/Chemical Parameters	Seafloor Parameters	Biological Parameters
size of farm (fish no. cage no.)	depth (minimum)	loading (of feed/faeces)	enrichment (bacterial mat)
cage layout (location, spacing)	flushing (tidal currents)	sediment (% organic carbon)	benthos (diversity/indicator sp)
other point sources (of pollutants)	exposure (to wind/waves)	redox (anoxic vs oxic)	biological diversity (fish)
husbandry (feeding, aesthetics etc.)	water quality (temp, sal, O_2)	grain size (erosion vs deposition)	biological diversity (invertebrates)

Minimal Impact	Moderate Impact	Significant Impact

METHODOLOGY

3.1 Field Crew

A four person crew (2 divers, 1 boat operator, 1 technician) travelled to each cage site at or near low tide in a dive boat equipped with surface fed air and communication equipment. All footwear was disinfected on board ship prior to accessing a cage operation. Staff interviewed owner/operators and gathered information regarding prevailing current flows, production practices etc. before beginning the sampling.

3.2 Laying of Transects

A 100m weighted leadline was laid on the seafloor from the edge of the oldest existing market fish cage set in the direction of the prevailing current. This line, marked in 5m increments, served to establish sampling stations at 10m, 25m and 100m. The transect line ensured that distances from the cages would remain relatively consistent when sampling and, served as a guide for the divers when collecting bottom samples or filming underwater. An "undercage" station was established by passing an anchored line between the first two sets of cages in the prevailing current direction which could then be tracked by the diver from his entry point at the end of the cages.

3.3 Sampling Procedure

Depths were recorded by a depth sounder or alternately a weighted line marked off in 0.5m increments. Water clarity readings were measured using a secchi disk. Water quality readings (temperature, salinity and dissolved oxygen) were taken from the surface, mid-depth and 1m above the seafloor using calibrated salinity and oxygen meters.

Using diver-held core tubes, three replicate sediment and benthos samples were collected under each cage and along the transect at the assigned 10m, 25m and 100m stations. The top 10 cm of the sediment cores were placed in plastic bags and later frozen. The benthic samples were collected and placed in one liter mason jars and preserved onboard in a 10% formalin solution.

During each dive, the diver's description of the bottom environment at each site was recorded by an on-board recorder. This information included descriptions of the presence of excess feed on the seafloor, bottom currents, extent of bacterial "mat" coverage, relative hardness of the bottom over distance, and occurrence of fish or macro invertebrates in the vicinity of the cages.

DISCUSSION OF RESULTS

Preliminary findings revealed that the salmon cage operations exhibited a broad spectrum of associated environmental impacts. The predominant factors which appeared to influence the degree of environmental impact at a site included: flushing rate of bottom currents (i.e. depositional qualities of seafloor), depth, feeding strategy (feeder type, feed type, rates, timing), net cleaning strategies, fish/cage rotation, distance from other point sources, cage configuration and exposure to wave/wind action.

Table 1 indicates the results of the overall impact ranking categories (low - high) based on the Aquaculture Monitoring Program assessment parameters. Environmental impact within each geographic area revealed a wide range of localized environmental effects due to some of the cage sitings being in relatively sheltered, shallow, poorly flushed parts of a cove as compared to others located in deep water and/or exposed to wind driven wave action and strong currents. This led to the observation that similar production activities at individual farms do not impact an area equally and that any extrapolation of results derived from studying one site does not provide an accurate account of predicted effects at another fish farm.

The relative environmental status of all cage sites is shown in Figure 3. Expressed as percentages, 16% of the sites showed highly impacted seafloor, 60% showed moderate impact and 23% showed minimal impact.

At the sites described as moderately impacted, degradation of the seafloor directly under the cages was found in the form of excess food and fish faeces. Bottom currents at these sites appeared insufficient to prevent gradual accumulation of excess organic matter. The result was an annual enrichment of the seabed, followed by an increase in bacterial activity and reduction in suitable habitat under cages for some native species. Although not measured, recovery from these conditions during the late fall to early spring was expected to occur.

At the sites described as highly impacted, the effects extended beyond the periphery of the cages and advanced stages of enrichment and degradation of the seafloor under cages. These sites were in need of remedial action, to alleviate potential growth, disease and ensuing mortality problems. The site operators were contacted and remedial action plans were begun. The degradation at the heavily impacted sites was not considered irreversible, and recovery of the seafloor was anticipated.

Beyond the highly enriched zone, usually found directly under the cage sets, a transition zone of moderate enrichment was identified at some sites. The density of the local on-bottom invertebrate community within this zone actually increased.

Table 1 - Overall Results From Primary Assessment Parameters

LOW IMPACT (n=11 sites)	avg
DEPTH	13.6
DEP.RANGE	8m - 27m
CURRENT	4.4
SEAFLOOR	4.1
BACTERIA	4.2
ORGANICS	46.3%
PRODUCTION	3.3
GAS	0%

MODERATE IMPACT (n=29 sites)	avg
DEPTH	11.5
DEP.RANGE	5.5m - 21m
CURRENT	3.5
SEAFLOOR	3.0
BACTERIA	2.9
ORGANICS	47.4%
PRODUCTION	2.8
GAS	10%

HIGH IMPACT (n=8 sites)	avg
DEPTH	9.5
DEP.RANGE	5.5m - 20m
CURRENT	2.2
SEAFLOOR	2.3
BACTERIA	2.1
ORGANICS	96.0%
PRODUCTION	2.6
GAS	100%

DESCRIPTION OF PARAMETERS

DEPTH - average depth at cage site at MLT

CURRENT - observed bottom current:
1 - very weak
5 - very strong

SEAFLOOR - 1 - highly depositional
5 - highly erosional

(Rank combines: % silt/clay, sediment depth/observation)

BACTERIA - areal coverage of Beggiatoa sp. to a distance of 50m from cages in prevailing current direction

ORGANICS - % increase in total organic matter from under cages compared to control station

PRODUCTION - estimated no. of fish (smolt and market) onsite at time of sampling
1 = + 100,000
2 = 76 - 100,000
3 = 51 - 75,000
4 = 26 - 50,000
5 = < 25,000

GAS - % of sites observed to have gases released from under cage sediments

Figure 3 - Relative Environmental Status of All Cage Sites

At the sites described as minimally impacted, very little disturbance of the seafloor was identified. Interestingly, there was no clear geographic distribution pattern for the majority of these relatively "clean" sites as seen in Figure 4 which depicts a range of environmental impact from low to high for the 10 areas monitored.

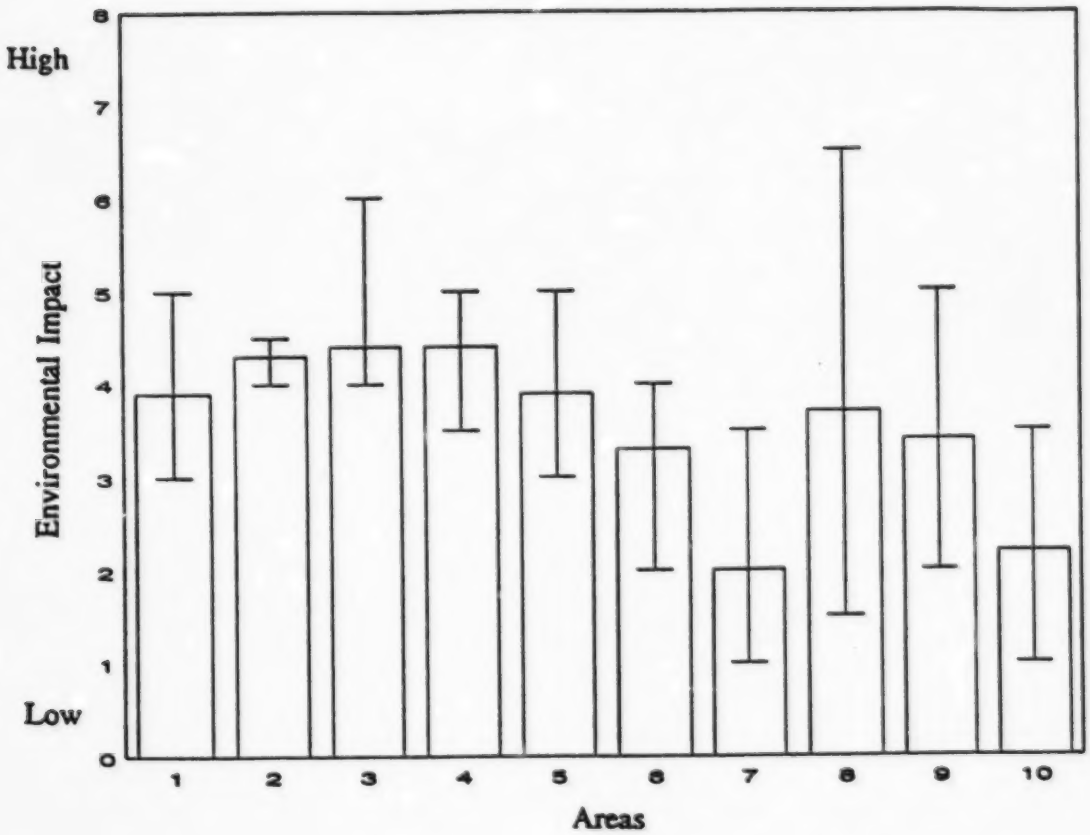
At distances greater than 50m, observable native species composition and abundance returned to "typical" background conditions in almost all cases. The pattern of enrichment over distance showed a wide range of variance per site and within each geographic area. In summary noticeable impacts from most sites were restricted to a 25m area around the cage sets with the greatest accumulation of organic material directly under the cages.

Typical inshore species found in Bay of Fundy waters which were observed in the area of the cages in 1991, included larger invertebrates such as sea urchins, mussels, starfish, whelks, sea cucumbers, rock crabs, lobsters, scallops and a multitude of other common seafloor dwelling organisms (Table 2). The fish species commonly seen in the these waters included sculpins, flounder, eelpouts, pollock, herring and other transient species.

Accumulation of wastes (uneaten food and faecal materials) from cage operations reduced the availability of seafloor habitat for seafloor dwelling organisms. The extent of habitat loss depended on local site conditions. In the most severe cases of enrichment, the macrofaunal (fish and invertebrate) community was likely to be impoverished and dominated by opportunistic species which were tolerant of enriched sediments.

Mobile bottom dwelling species such as shorthorn and longhorn sculpins and the winter flounder were observed at all but 2 of the more heavily impacted sites. These species were regularly seen feeding on excess feed deposited under cages. Their role in reducing potential enrichment at a site was noted. Schools of pollock were also frequently observed at cage sites and were also observed feeding on feed lost outside the cages in the water column.

Figure 4 - Range of Environmental Impact by Area



Cage Culture Area:

1. L'Etang Estuary
2. Limekiln Bay
3. Bliss Harbour
4. Beaver Harbour
5. Back Bay
6. L'Etite Passage
7. Passamaquoddy Bay
8. Deer Island
9. Campobello Island
10. Grand Manan Island

Table 2 - List of More Common Fish/Macro Invertebrate Species Observed at the Cage Sites

SPECIES	OCCURRENCE
Winter Flounder Longhorn Sculpin Pollock Blue Mussel Northern Seastar Atlantic Rock Crab Sand Shrimp	Very common
Shorthorn Sculpin Green Sea urchin Northern Sea cucumber Common Northern Whelk Northern Moon Snail	Common
Lumpfish Herring (juv.) Northern Lobster Giant Scallop Common Sand dollar Acadian Hermit Crab	Occasional
4-Beard Rockling Ocean Pout Grubby Radiated Shanny Skate sp.? Wrymouth Horse Mussel Common Starfish Basket Star Common Seastar Sea Peach Sea Potato Plumose Anemone Dahlia Anemone	Rare

CONCLUSIONS

The results of the 1991 Aquaculture Monitoring Program indicated that disturbances of the natural environment by cage aquaculture were of locally varying magnitudes, with the majority of sites showing moderate degradation in the immediate vicinity of the cage sets.

The degree of degradation varied at each site and was less a function of the designated geographic areas within the Bay of Fundy than of site location, the physical and oceanographic conditions prevalent there and individual husbandry practices. The cumulative effect of all the farms in one geographic area requires further investigation in order to determine overall sustainable development levels in a given geographic area.

Future monitoring will, therefore, place emphasis on incorporating site specific production/operational information supplied by each operator in order to provide a more comprehensive picture of each site's carrying capacity.

In addressing demands for new sites, cage culturists have historically sought a protected bay for siting a farm which can feature slow flushing and semi-enclosed waters prone to waste and sediment accumulation. To avoid "self-polluting" situations, the results support the contention that new areas should be sought which exploit more exposed, deeper parts of the Bay of Fundy that exhibit more regular tidal flushing. However, the area available for salmon farming is currently limited pending proven technological advances which would allow exploitation of these offshore waters.

The health of both the aquaculture industry and the marine environment upon which it depends can be protected through the adherence to good husbandry and environmental protection practices.

Continued monitoring of the cage aquaculture industry will provide a better understanding of the carrying capacity of this area of the Bay of Fundy which in turn will assist regulatory agencies in defining more precisely the sustainability of the industry.